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ABSTRACT

This study aimed at examining the merit of crop diversification as a strategy for agricultural growth in Bangladesh. Specifically, the existence of economies of diversification, scale economies and diversification efficiencies at the farm level were examined using a stochastic input-distance function approach. The results reveal strong evidence of diversification economies amongst most crop enterprises except the combination of modern rice and modern wheat enterprises. Ray economies of scale exist in Bangladeshi cropping system. Also, significant are efficiency gains made from diversification among cropping enterprises. The key policy implication is that crop diversification should be a desired strategy for agricultural growth in Bangladesh. Development of the rural infrastructure is also essential as this will not only improve technical efficiency but may also synergistically promote crop diversification by opening up opportunities for technology diffusion, marketing, storage and resource supplies.

JEL classification: O33; Q18; C21

Keywords: Diversification economies, Diversification efficiencies, Stochastic input distance function, Crop diversification, Bangladesh.

1. Introduction

The economy of Bangladesh is largely dependent on agriculture. Although, rice production dominates the farming system of Bangladesh, accounting for 70% of the gross cropped area (BBS, 2001), several other crops are also grown in conjunction with rice in order to fulfil a dual role of meeting subsistence as well as cash needs. Since the beginning of the 1960s, Bangladesh has pursued a policy of rapid technological progress in agriculture, leading to diffusion of a rice-based 'Green-Revolution' technology package. As a result, farmers concentrated on producing modern varieties of rice all year round covering three production seasons (*Aus* - pre-monsoon, *Aman* - monsoon and *Boro* - dry winter), particularly in areas that are endowed with supplemental irrigation facilities. This raised concern regarding the loss of crop diversity, consequently leading to an unsustainable agricultural system. For example, Husain et al., (2001) noted that the intensive monoculture of rice led to a displacement of land under less productive non-rice crops such as pulses, oilseeds, spices and vegetables, leading to an erosion of crop diversity, thereby, endangering the sustainability of crop-based agricultural production system. Mahmud et al., (1994: 02) also noted that "the area under non-cereal crops has continuously fallen since the late 1970s, mainly due to the expansion of irrigation facilities, which has led to fierce competition for land between modern *Boro* season (dry winter) rice and non-cereals". However, an analysis of the level of crop diversification between the two Agricultural Censuses of 1960 and 1996 reveals that the level of crop diversity has actually increased by 4.5 percent over the 36 year period (Table 1). The Herfindahl index of crop diversification is computed at 0.59 in 1960 and 0.54 in 1996. To summarise the main changes between the two census periods were: (i) an increased share of small farms, (ii) a shrinking of average farm size per household, (iii) a decline in total net cropped area, (iv) an increase in cropping intensity, (v) an increased diffusion of modern rice varieties which replaced traditional rice area to a large extent, (vi) a dramatic increase in modern wheat area, and (vii) only a two percent decline in the share of area under non-cereal crops.

Although many non-cereal crops (e.g., potatoes, vegetables, onions and cotton) are more profitable (both in economic and financial terms) than modern rice cultivation, expansion of these crops remains limited because of the associated high risk as well as incompatibility of the existing irrigation system to produce non-cereals in conjunction with rice (Mahmud et al., 1994). However, it has been increasingly recognized that, under non-irrigated or semi-irrigated conditions, better farming practices and varietal improvements in non-cereal crops will be more profitable and could lead to crop diversification as a successful strategy for the future growth and sustainability of Bangladeshi agriculture (MoA, 1989; Mahmud et al., 1994; PC, 1998). The Fifth Five Year Plan (1997–2002) set specific objectives to attain self-sufficiency in foodgrain production along with increased production of other nutritional crops, as well as to encourage the export of vegetables and fruits, keeping in view domestic consumption demand and nutritional requirements (PC, 1998). The Plan also earmarked Tk 1,900 million (US$ 41.8 million) accounting for 8.9 percent of the total agricultural allocation to promote crop diversification. Such an emphasis at the policy level points towards the importance of determining the merits of crop diversification at the farm level. We examine this merit in terms of gains in economies of diversification and technical efficiency, so that an informed judgment can be made about the suitability of crop diversification as a desired strategy for promoting agricultural growth in Bangladesh.

Studies on crop diversification in the literature are diverse and focus on its impact either on income or overall production. For example, Guvele (2001) concluded that crop diversification reduces variability in income in Sudan. Van den Berg et al., (2007) concluded that diversification into high-value vegetable crops and away from rice will enable Chinese farms to sustain a reasonable income level given present farm-size distributions. Kar et al., (2004) concluded that crop diversification in upland areas serves as a good measure to mitigate drought, as well as increasing water use efficiency, whilst also increasing the overall yield of the system in India. However, studies examining the explicit relationship between crop diversification and production efficiency at farm level are few, with mixed conclusions. For example, Coelli and Fleming (2004) concluded that crop diversification significantly improves technical efficiency on farms in Papua New Guinea, whereas Llewelyn and

Williams (1996) and Haji (2007) concluded that crop diversification significantly reduces technical efficiency in Indonesian farms and allocative and economic efficiency in Ethiopian farms, respectively. It is expected that individual economies within the developing world are unlikely to demonstrate a uniform relationship between crop diversification and production efficiency. The contrasting evidence provided by the aforementioned studies proves the point. Therefore, it is important to determine the merits of crop diversification case by case, particularly when the government of Bangladesh is keen to adopt crop diversification as a strategy for agricultural growth as well as to promote sustainability (MoA, 1998; Mahmud et al., 1994).

Given this backdrop, the study is aim to examine: (a) the existence of economies of diversification among crop enterprises; and (b) the impact of diversification on technical efficiency in farming in Bangladesh. The present study will, therefore, be a valuable addition to the source of knowledge on the performance of the agricultural sector, which is largely diversified in nature, such as Bangladesh.

2. Methodology

2.1 Data and the study area

The study is based on farm-level cross section data for the crop year 1996 collected from three agro-ecological regions of Bangladesh. The survey was conducted from February to April 1997. Samples were collected from eight villages of the Jamalpur Sadar sub-district of Jamalpur, representing wet agro-ecology, six villages of the Manirampur sub-district of Jessore, representing dry agro-ecology, and seven villages of the Matlab sub-district of Chandpur, representing wet agro-ecology in an agriculturally advanced area. A multistage random sampling technique was employed to locate the districts, the *Thana* (sub-districts), and then the villages in each of the three sub-districts, and finally the sample households. A total of 406 households[1] from these 21 villages were selected. Detailed crop input-output data at the plot level for individual farm households were collected for ten crop groups[2]. The dataset also includes information on the level of infrastructural development[3] and soil fertility determined from soil samples collected from representative locations in the study villages[4].

2.2 Analytical framework

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[1] The sample households were selected based on the information on the total number of households including their land ownership categories, which were obtained from BRAC (a national non-governmental organization). Then a stratified random sampling procedure was applied using a formula from Arkin and Colton (1963) that maximizes the sample size with a 5% error limit. Farm size categories (large, medium, and small farmers) were used as the strata (for details, see Rahman, 1998).

[2] The crop groups are: traditional rice varieties (Aus – pre-monsoon, Aman – monsoon, and Boro – dry seasons), modern/high yielding rice varieties (Aus, Aman, and Boro seasons), modern/high yielding wheat varieties, jute, potato, pulses, spices, oilseeds, vegetables, and cotton. Pulses in turn include lentil, mungbean, and gram. Spices include onion, garlic, chilli, ginger, and turmeric. Oilseeds include sesame, mustard, and groundnut. Vegetables include eggplant, cauliflower, cabbage, arum, beans, gourds, radish, and leafy vegetables.

[3] A composite 'index of underdevelopment of infrastructure' was constructed using the cost of access approach. A total of 13 elements are considered for its construction. These are primary market, secondary market, storage facility, rice mill, paved road, bus stop, bank, union office, agricultural extension office, high school, college, thana (sub-district) headquarters, and post office. A total cost (*TC*) of access was computed by summing up individual costs (IC_i) of access (i.e., distance x cost per km). Then, *TC* was correlated with costs for each element (IC_i) which provided individual correlation coefficients (W_i). The final index (INF) was then calculated by summing up all the ICs (each weighted by its correlation coefficient) and divided by sum of all correlation coefficients (see Ahmed and Hossain, 1990 for further details).

[4] The 'soil fertility index' was constructed from test results of soil samples collected from the study villages during the field survey. Ten soil fertility parameters were tested. These are soil pH, available nitrogen, available potassium, available phosphorus, available sulphur, available zinc, soil texture, soil organic matter content, cation exchange capacity of soil, and electrical conductivity of soil (for details of sampling and tests, see Rahman and Parkinson, 2007 and Rahman, 1998).

Sources of productivity growth can be decomposed into two principal components: technical efficiency (TE) and technical change (TC). TE can be interpreted as a relative measure of managerial ability for a given level of technology, whereas TC evaluates the effect on productivity arising from the adoption of new or improved production processes (Bravo-Ureta et al., 2007). The gains in TE are derived from improvements in decision making, which in turn are assumed to be linked to a host of socio-economic conditions, e.g., knowledge, education, and experience. On the other hand, TC relates to investment in research and technology (Nishimazu and Page, 1982 cited in Bravo-Ureta et al., 2007). In this study, we are interested in examining whether crop diversification leads to gains in TE (i.e., diversification efficiencies), as well as whether diversification into various crop enterprises lead to gains in economies of scale (i.e., diversification economies).

To examine the existence of diversification economies and diversification efficiencies, a multi-output, multi-input production technology specification is required as opposed to the commonly used single-output, multi-input production technology. The use of a distance function approach (either output-orientated or input-orientated) circumvents this problem and can be analyzed using either parametric or non-parametric methods. Also, the main advantage of a distance function approach is that the production frontier can be estimated without assuming separability of inputs and outputs (Kumbhakar, et al., 2007). An output oriented approach to measure technical efficiency is appropriate when output is endogenous (e.g., revenue maximization case) but inputs are exogenous, whereas an input oriented approach is appropriate when inputs are endogenous (e.g., cost minimization case) but output is exogenous (Kumbhakar et al., 2007). We have selected the use of an input-orientated stochastic distance function to address these research questions. This is because, in an economy like Bangladesh, on the one hand, inputs are highly scarce, particularly the land input, and on the other hand, farmers are often constrained by cash/credit (Rahman, 1998). Therefore, it is logical to assume that cost minimization is the prime concern.

We begin by defining the production technology of the farm using the input set, L(y), which represents the set of all input vectors, $x \in R_{+}^{K}$, which can produce the output vector $y \in R_{+}^{M}$. That is,

$$L(y) = \{x \in R_{+}^{K} : x\, can\, produce\, y\} \qquad (1)$$

The input-distance function is then defined on the input set, L(y), as

$$D_I(x, y) = \max\{\rho : (x/\rho) \in L(y)\} \qquad (2)$$

$D_I(x,y)$ is non-decreasing, positively linearly homogenous and concave in x, and increasing in y. The distance function, $D_I(x,y)$, will take a value which is greater than or equal to one if the input vector, x, is an element of the feasible input set, $L(y)$. That is, $D_I(x,y) \geq 1$ if $x \in L(y)$. Furthermore, the distance function will take a value of unity if x is located on the inner boundary of the input set.

2.3 Economies of diversification

Coelli and Fleming (2004) presented a measure of economies of diversification for Papua New Guinea farmers relative to an input distance function which, in principle, can be conceived of as the lower-bound estimate of the traditional cost function measure of scope economies. The partial derivative of the input distance function (defined in the previous section) with respect to the *i*th output is generally negative, implying that the addition of an extra unit of output, with all other variables held constant, reduces the amount by which we need to deflate the input vector to put the observation onto the efficient frontier. Thus, the second cross partial derivative of the input distance function, with respect to output, needs to be positive, to provide evidence of economies of diversification. Economies of diversification exist between outputs *i* and *j* if (Coelli and Fleming, 2004):

$$\frac{\partial^2 D}{\partial Y_i \partial Y_j} > 0, \quad i \neq j, \quad i, j = 1,....m. \qquad (3)$$

2.4 Diversification efficiencies

In addition to the examination of diversification economies, another key question of interest is to investigate whether farming inefficiencies are related to the degree of diversification (or specialization), since the literature on this issue is mixed. Specialization of farming activity may lead to lower inefficiency or vice versa. The expectation is that specialization in production leads to efficiency gains in the division of labour and management of resources (Coelli and Fleming, 2004). Diversification efficiency, which works in the opposite direction to specialization efficiencies, may be derived from intimate knowledge of farmers' yet uncertain production environment and the ability to adjust their labour and other resources to various farming activities.

A Herfindahl index is used to represent the specialization variable. Although, this index is mainly used in the marketing industry to analyze market concentration, it has also been used to represent crop diversification and/or concentration[5] (e.g., Llewelyn and Williams, 1996; Bradshaw, 2004). The Herfindahl index (D_H) is represented as $D_H = \sum \alpha_i^2$, $0 \leq D_H \leq 1$, where α_i represents the area share occupied by the *i*th crop in total area *A*. A zero value denotes perfect diversification and a value of 1 denotes perfect specialization. Land is the scarcest input in Bangladesh compared with any other resource requirements. In fact, the land-person ratio in Bangladesh is one of the lowest in the world,

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[5] The Ogive index, which is defined as a concentration of output shares of various enterprises, can also be used to represent the specialization variable (e.g., Coelli and Fleming, 2004).

estimated at only 0.12 ha (FAO, 2001). Therefore, the selection of Herfindahl index to represent crop diversification is correctly justified[6].

2.5 Other factors explaining efficiencies

In addition to variables representing crop diversification (or specialization), a number of other explanatory factors representing farmers' socio-economic circumstances may affect efficiency. These are: amount of land owned by the farmer, farmers' education and farming experience, family size, extension contact, index of infrastructure development (defined in footnote 3), index of soil fertility (defined in footnote 4), and the proportion of non-agricultural income of the household. Choice of these variables is based on the existing literature and the justification for their inclusion is briefly discussed as follows.

In Bangladesh, land ownership serves as a surrogate for a number of factors as it is a major source of wealth and influences crop production (Hossain, 1989; Ahmed and Hossain, 1990). The size-productivity relationship in Bangladesh varies across regions depending on the level of technological development and environmental opportunities. The relationship is positive in technologically advanced regions, whereas the classic inverse relationship still exists in backward areas (Toufique, 2001). We included the 'amount of land owned' variable to test whether farm size influences technical efficiency (e.g., Ali et al., 1994; Ali and Flinn, 1989; Wang et al., 1996).

Use of the education level of farmer as a technical efficiency shifter is fairly common (e.g., Asadullah and Rahman, 2008; Wang et al., 1996; Wadud and White, 2000). The education variable is also used as a surrogate for a number of factors. At the technical level, access to information as well as capacity to understand the technical aspects related to crop production is expected to improve with education, thereby, influencing technical efficiency.

[6] We have also analysed the data using the Ogive index of output concentration, which provided almost identical results.

The justification for including farming experience is straightforward. Experienced farmers are more likely to be wiser in decisions regarding the use and allocation of scarce inputs (e.g., Ali et al., 1994; Llewelyn and Williams, 1996; Coelli and Fleming, 2004).

According to the Chayanovian theory of the peasant economy, higher subsistence pressure increases the tendency to adopt new technology and this has been found to be the case in Bangladesh (Hossain, et al., 1990). The subsistence pressure variable (defined as family size per household) was incorporated to test whether it influences technical efficiency as well (e.g., Wang et al., 1996; Ali et al., 1994).

Agricultural extension can be singled out as one of the most important sources of information dissemination directly relevant to agricultural production practices, particularly in nations like Bangladesh where farmers have very limited access to information. This is reinforced by the fact that many studies found a significant influence of extension education on adoption of modern technologies (e.g., Baidu-Forson, 1999; and Adesina and Zinnah, 1993). Therefore, this variable was incorporated to account for its influence on technical efficiency in order to make a case for strengthening extension services and networks, if its coefficient shows positive sign (e.g., Rahman, 2003; Ali et al., 1994; Ali and Flinn, 1989).

The level of rural infrastructure is a key limiting factor in the development of Bangladeshi agriculture (Ahmed and Hossain, 1990). Areas with better infrastructure can realize higher productivity levels than underdeveloped areas for several reasons. For example, extension information reaches them more easily, and/or delivery of modern inputs such as fertilizers and pesticides is timelier. Soil fertility is also a key factor that exerts a positive influence on productivity (e.g., Rahman, 2005; Rahman and Parkinson, 2007). The indices of 'underdevelopment of rural infrastructure' and 'soil fertility' were incorporated to test their independent influence on technical efficiency.

The percentage of income earned off-farm was included to reflect the relative importance of non-agricultural work in these farm households. Household with a higher share of non-agricultural income are reported to operate at lower level of technical efficiency (e.g., Ali and Flinn, 1989; Wang et al., 1996).

3. The empirical model

A multi-output, multi-input stochastic distance function was used to compute the farm specific technical efficiency index. The empirical model is specified using a translog stochastic input distance function allowing for all possible interactions. All the variables were mean-corrected prior to estimation, so that the coefficients of the first-order terms can be directly interpreted as elasticities or marginal effects. The translog stochastic input distance function, dropping the j^{th} subscript for individual farms, is specified as:

$$\ln d = \alpha_0 + \sum_{i=1}^{7} \alpha_i \ln X_i + \frac{1}{2}\sum_{i=1}^{7}\sum_{j=1}^{7} \alpha_{ij} \ln X_i \ln X_j + \sum_{k=1}^{4} \beta_k \ln Y_k + \frac{1}{2}\sum_{k=1}^{4}\sum_{l=1}^{4} \beta_{kl} \ln Y_k \ln Y_l + \sum_{i=1}^{7}\sum_{k=1}^{4} \tau_{ik} \ln X_i \ln Y_k \quad (4)$$

where Xs are inputs and Ys are outputs. The seven inputs used in the analyses are: X_1 = land under all crops (ha), X_2 = amount of fertilizers (kg), X_3 = amount of total (family supplied + hired) labour (person-days), X_4 = animal power services (animal-pair days), X_5 = irrigation (taka), X_6 = pesticides (taka) and X_7 = seeds (taka). The four outputs are: Y_1 = traditional rice (kg), Y_2 = modern rice (kg), Y_3 = modern wheat (kg), and Y_4 = cash crops[7] (includes jute, cotton, oilseeds, spices, pulses, potatoes, and vegetables) (taka).

Following Coelli and Perelman (1999), we set $-\ln d = v - u$, and impose the restriction required for homogeneity of degree +1 in inputs $(\sum_{i=1}^{7} \alpha_i = 1)$ to obtain the

[7] The gross value of each output is used to construct this compound (aggregate) variable, and is expressed as Taka per farm.

estimating form of the stochastic input distance function (i.e., normalizing the input vectors by any one of the inputs, specifically the land input X_1):

$$-\ln X_1 = \alpha_0 + \sum_{i=2}^{7} \alpha_i \ln\left(\frac{X_i}{X_1}\right) + \frac{1}{2}\sum_{i=2}^{7}\sum_{j=2}^{7} \alpha_{ij} \ln\left(\frac{X_i}{X_1}\right)\ln\left(\frac{X_j}{X_1}\right) + \sum_{k=1}^{4} \beta_k \ln Y$$
$$+\frac{1}{2}\sum_{k=1}^{4}\sum_{l=1}^{4} \beta_{kl} \ln Y_k \ln Y_l + \sum_{i=2}^{7}\sum_{k=1}^{4} \tau_{ik} \ln\left(\frac{X_i}{X_1}\right)\ln Y_k + v - u \qquad (5)$$

where the *v*s are assumed to be independently and identically distributed with mean zero and variance, σ_u^2 ; and the *u*s are technical efficiency effects that are assumed to be identically distributed such that *u* is defined by the truncation at zero of the normal distribution with unknown variance, σ_u^2, and unknown mean, μ, defined by:

$$\mu = \delta_0 + \sum_{m=1}^{9} \delta_m Z_m \qquad (6)$$

where Z_1 = amount of land owned (ha), Z_2 = education of farmer (years of completed schooling), Z_3 = experience of farmer (years), Z_4 = family size (persons), Z_5 = index of underdevelopment of infrastructure (number), Z_6 = index of soil fertility (number), Z_7 = extension contact dummy (1 if had any contact (including training) in past one year, 0 otherwise), and Z_8 = share of non-agricultural income (percent) and Z_9 = Herfindahl index of crop diversification (number).

We follow Battese and Corra (1977) in replacing the variance parameters, σ_v^2 and σ_u^2, with $\gamma = \frac{\sigma_u^2}{(\sigma_v^2 + \sigma_u^2)}$ and $\sigma_s^2 = \sigma_v^2 + \sigma_u^2$ in the estimating model. The input distances are predicted as (Coelli and Perelman, 1999): $d = E[\exp(u) \mid e]$, where $e = v - u$. The inverse of these input distances *(d)* are the technical efficiency scores of each individual farm, which have a feasible range from zero to unity, with unity being fully efficient (Coelli and Fleming, 2004). Estimates of the parameters of the model were obtained using maximum likelihood procedures, detailed by Coelli and Perelman (1999). STATA Software Version 8 was used for the analyses (Stata Corp, 2003).

4. Results

Prior to the presentation of results, we provide a summary of the key characteristics of the sampled farmers (Table 2). The average farm size is 0.98 ha; the amount of land owned per farm is 0.65 ha; the average level of education is less than four years; experience in farming is 26 years; average family size is six persons; 22 percent of income is derived off-farm; and only 13 percent of farmers have had contact with extension officers during the past year. The computed Herfindahl index of crop diversification ranges from 0.18 to 1.00 with mean score of 0.60 indicating strong presence of diversification among enterprises.

The results of the maximum likelihood estimation (MLE) of the stochastic input distance function model are presented in Table 3. Two sets of hypotheses were tested using the Likelihood Ratio tests. First, we tested for the presence of inefficiencies in the model. The parameter γ is the ratio of error variances from Eq. (5). Thus, γ is defined between zero and one, where if $\gamma = 0$, technical inefficiency is not present, and where $\gamma = 1$, there is no random noise. The test of significance of the inefficiencies in the model (H_0: $\gamma = \mu = 0$) was rejected at the 1 percent level of significance, indicating that the MLE is a significant improvement over an Ordinary Least Squares (OLS) specification and inefficiencies are present in the model. The calculated value of the test statistic is 71.67, which is greater than the critical value obtained from Table 1 of Kodde and Palm (1986) with three restrictions. Second, we tested the joint significance of all the variables including crop diversification index and the null hypothesis (H_0: $\delta_m = 0$ for all m) was rejected at the 1 per cent level of significance. The calculated value of the test statistic is 33.28, which is greater than the critical value of χ^2 with 9 restrictions, implying that the inclusion of these variables to explain inefficiency is justified.

One-third of the estimated coefficients are significantly different from zero at the 10 percent level at least. The signs of the coefficients on the first order terms of the input and output variables are consistent with theory. For example, a positive coefficient on any input variable implies substitutability of that input with land. On the other hand, a negative coefficient on any output variable implies that a reduction in land area is positively associated with a reduction in that output. The coefficients on a number of interaction variables (second order terms) are also significantly different from zero, thereby, confirming non-linearities in the production process, and hence, justifying the use of the flexible translog specification. It should be noted that in a flexible translog function model with large number of inputs and outputs, violation of the regularity condition in some inputs and outputs are unavoidable. Table 3 shows that the labour input and modern wheat output violates the expected regularity conditions (i.e., positive sign on the input coefficients and negative sign on the output coefficients). However, since the value of the coefficients on these two variables is not significantly different from zero, it may not be the true relationship. Another point to note is that the results presented in Table 3 are true at the point of approximation of the translog function.

The sum of the coefficients on four output variables (traditional rice, modern rice, modern wheat and cash crops) is 0.78 (Table 3). The inverse of this figure (1.28) provides a measure of ray scale economies (at the sample means), suggesting increasing returns to scale. The implication is that the farmers are likely to benefit from significant economies of scale (Coelli and Fleming, 2004).

4.1 Economies of diversification

Following Coelli and Fleming (2004), we calculated the measure of diversification economies (defined in Eq. 3) using the coefficient estimates reported in Table 3 for each pair of crop enterprises (outputs) at the mean values of the sample data[8]. The result of this exercise is presented in Table 4. Unlike Coelli and Fleming (2004), we found strong evidence of economies of diversification across most crop combinations except modern rice and modern wheat crops. The possible explanation is that, modern rice (particularly, the *Boro* season rice) and modern wheat are grown in the same winter season and, therefore, there are potentially clashes with resource allocation requirements, particularly the land and labour inputs. Since, double log specification is used to compute these diversification economies, the coefficients can be read as diversification elasticities. For example, the diversification economies between traditional and modern rice is estimated at 0.02. The implication is that a one percent increase in traditional rice output will reduce the marginal use of inputs for producing modern rice by 0.02 percent. Given the estimated coefficients, it seems that the economic gain of diversification is highest with the combination of modern rice and cash crops, as expected.

Table 5 presents input use rates classified by the level of farm diversification. We designated farms with the Herfindahl index ≥ 0.90 as 'specialized farms' (who were largely modern rice producers) and the remaining as 'diversified farms'. It is clear from Table 5 that the operational size of diversified farms is significantly higher and the use rates of inputs per hectare, except seeds and irrigation, are significantly lower. The use rates of labour, animal power services, and fertilizers are 25, 13 and 19 percent lower among diversified farms compared with those of specialized farms. Also, pesticide use rates are 113 percent higher for the specialized farms. Although, gross value of output is significantly higher for specialized farms, the profits are similar between specialized and diversified farms, due to significantly lower use of inputs by the latter. It is also clear from Table 5 that technical efficiency is significantly higher for diversified farms. The mean technical efficiency score for specialized

[8] Details of the derivation of these estimates and their respective standard errors are presented in Appendix A.

farms is computed at 0.52 compared with 0.95 for the diversified farms. This finding also implies that the diversified farms are already operating at a very high level of efficiency, with very little to improve through resource reallocation.

4.2 Diversification efficiencies

A plot of the distribution of technical efficiency scores is presented in Figure 1. The efficiency scores range from 33 to 98 percent, with a mean score of 84 percent[9]. This estimated mean level of technical efficiency is higher than the estimates of technical efficiency for producing only rice crops in Bangladesh. For example, technical efficiency of rice production is estimated at 69.4 percent (Coelli et al., 2002) and 78.9 percent (Wadud and White, 2000) in Bangladesh. The implication is that, although there is substantial opportunity to expand crop output without additional resources, the results of earlier studies on Bangladesh somewhat overstated the scope to expand overall output by concentrating on rice crops only, which corroborates the findings of Bravo-Ureta et al., (2007). Bravo-Ureta et al., (2007), using a meta-analysis of 167 efficiency studies conducted worldwide, concluded that frontier models with grain crops present, on average, lower mean technical efficiency scores than those for 'other crops', 'dairy and cattle', or 'whole farm' categories. The average mean technical efficiency in 'rice farming' was estimated at 72.4 percent compared with 'other crops' farming at 74.4 percent, 'dairy and cattle' enterprises at 80.6 percent and for the 'whole farm' at 76.8 percent (Bravo-Ureta et al., 2007). The distribution of the efficiency score has a long tail at the lower end of the efficiency spectrum (Figure 1). About 25 percent of the farmers are producing at an efficiency level of less than 60 percent. However, two-

[9] The correlation between the computed technical efficiency scores from model with the Herfindahl index and the model with the Ogive index is estimated at 0.98 ($p<0.01$). Therefore, we have decided to report only the results of the model using the Herfindahl index.

thirds of the farmers are producing at the top decile range (90 percent and above), which is encouraging.

The results of the inefficiency effects model are presented in the lower panel of Table 3. It is clear from Table 3 that significant diversification efficiency exists in Bangladeshi crop production. The positive coefficient on the Herfindahl index indicates that technical inefficiency is positively associated with specialization, which implies that crop diversification, therefore, significantly improves technical efficiency. This result is consistent with Coelli and Fleming (2004) but not with Llewelyn and Williams (1996) and Haji (2007).

Farmers located in regions endowed with better infrastructure are more technically efficient, as expected[10] (Table 3). The implication is that technical efficiency would be adversely affected by not having inputs to use at the correct time, or not at all. This finding is consistent with the existing literature (e.g., Ali and Flinn, 1989; Wang et al., 1996; Rahman, 2003).

5. Discussion and policy implications

The aim of this study is to examine whether crop diversification is a desired strategy for agricultural growth in Bangladesh. Specifically, we investigated the existence of economies of diversification and diversification efficiencies in farming systems that produce a mix of crops to cover subsistence as well as cash needs. We find strong evidence of diversification economies in most of the crop enterprises, except the modern rice and modern wheat combination. In other words, specialization (i.e., intensive modern rice monoculture in our case) has two effects on overall productivity. The first is a negative impact on productivity via loss of diversification economies. The second effect is to reduce overall productivity via loss of diversification efficiencies (Coelli and Fleming, 2004). The economy

[10] This index is constructed as the "underdevelopment of infrastructure". Therefore, a positive sign on the coefficient of this variable implies a positive impact on technical efficiency.

of diversification perhaps is realized in two ways: (a) by effective use of household labour in lean seasons and avoiding bottlenecks in labour usage; and (b) by using less purchased inputs, particularly pesticides and fertilizers. When a farm diversifies into a combination of subsistence and cash crop production, the farmer uses the opportunity to select enterprises that complement each other, given the nature of seasonality in demand for labour in particular. For instance, modern rice production exerts significant pressure on labour requirements during transplanting and harvesting seasons, whereas traditional rice is largely broadcasted and uses large amounts of labour during the harvesting period only. Evidence of diversification economy observed between traditional and modern rice enterprises is largely due to the practice of producing traditional and modern rice in the main growing season, the Aman season (monsoon season), where the irrigation requirement for the latter is substituted to a large extent by rainfall. Also, labour requirements for both can be economised. This phenomenon perhaps partly explains stagnancy in the overall coverage of modern rice at 69 percent of the total rice area, and the figure is even lower at only 43 percent during the Aman season (BBS, 2001).

The cropping system in Bangladesh is largely influenced by access to water. The cropping pattern can be broadly classified into cropping under rainfed and irrigated conditions, which again vary according to the degree of seasonal flooding. As mentioned earlier, an apparent paradox exists in that, although many non-cereals are more profitable than producing modern rice, their expansion has stagnated due to the incompatibility of the existing modern irrigation systems (Mahmud et al., 1994). In fact, areas where modern irrigation is non-existent or unreliable, modern wheat is the desired crop and this provides higher profitability (Morris et al., 1996). In general, the proportion of non-cereal crops is lower under irrigated conditions as compared with rainfed conditions (Mahmud et al., 1994). The sample households of this study also demonstrated that the cropping system is highly diverse in areas with poor irrigation facilities. For example, cropping diversity is significantly lower in the Comilla region in comparison with the Jamalpur and Jessore regions. This is because some of the villages in the Comilla region fell within the Meghna-Dhonagoda Flood Control, Drainage and Irrigation (FCD/I) project, which resulted in the dominance of modern rice monoculture throughout the crop year because of the assured availability of water for irrigation at a cheap rate (Rahman, 1998).

An important issue that limits the scope to expand non-cereals is the existence of the price risk associated with uncertainties in marketing, particularly for perishable crops such as vegetables. In fact, annual variability in harvest prices is as high as 15–25 percent for most fruits and vegetables (including potatoes) and 20–40 percent for spices, as compared with only 5–6 percent for cereals (Mahmud et al., 1994). This perhaps explains the decline in the area under spices between the census years (Table 1). Mahmud et al., (1994) further noted that the price shock is most severe at the level of primary markets during harvest seasons. Delgado (1995) stressed the need for addressing marketing issues and constraints as a priority option to promote agricultural diversification in sub-Saharan African regions. This is because in the absence of improved markets, the agricultural sector is likely to suffer from demand constraints as well as a weak supply response, thereby, affecting growth. One way to lower the price risk is through improvements in marketing, which in turn depends on the development of the rural infrastructure. The results of this study clearly reveal that infrastructure significantly improves technical efficiency, which is consistent with the existing literature (e.g., Ali and Flinn, 1989; Wang et al., 1996; Coelli et al., 2002; Rahman, 2003; Wadud and White, 2000). Infrastructure development in turn may also open up opportunities for marketing, storage and resource supplies, which would complement crop diversification. For example, Ahmed and Hossain (1990) concluded that farms in villages in Bangladesh with relatively well developed infrastructure use relatively greater amounts of fertilizer and market a higher percentage of their agricultural products. Evenson (1986) noted a strong relationship between roads and increased agricultural production in the Philippines. He claimed that a 10 percent increase in roads would lead to a 3 percent increase in production in the Philippines. Ahmed and Donovan (1992: 31) concluded that “the degree of infrastructural development is in reality the critical factor determining the success of market-oriented sectoral and macroeconomic policies in the developing world”.

It should also be noted that non-cereals produced by most farmers comprised largely traditional varieties, which are low yielding. Strategies to improve varieties of non-cereals, therefore, provides further potential to improve productivity gains from diversification. Conventionally, the R&D activities in Bangladesh are largely concentrated on developing modern rice varieties to the neglect of most other crops. Among the non-cereals, modern technology is only well established in potato cultivation (Mahmud et al., 1994). The Bangladesh Agricultural Research Institute (BARI) is entrusted with the responsibility of developing modern varieties of all cereal and non-cereal crops except rice and jute. To date, a total of 131 improved varieties of various cereal and non-cereal crops have been developed and released by BARI, although only two-thirds of these have only being released since 2006 (Hossain, et al., 2006). However, there is a need to examine the impact of these new releases on farmers’ portfolios of crop choices at the farm level, because the technical and socio-economic constraints on the diffusion of these technologies remain unexplored and less understood (Mahmud et al., 1994).

The results of this study also reveal that increasing returns to scale are evident in Bangladeshi crop production. The implication is that Bangladeshi farmers could gain by increasing their farm sizes. Conventionally, either constant or decreasing returns to scale in Bangladesh are usually reported in the literature, although this remains limited to examining rice production only (e.g., Wadud and White, 2000; Coelli et al., 2002; Rahman, 2003; Asadullah and Rahman, 2008).

A clear policy implication that emerges from the results of this study is that crop diversification should be a desired strategy to promote agricultural growth in Bangladesh, as it has a positive impact on resource economy as well as technical efficiency. The challenge, however, remains how to succeed with this strategy. The recent thrust at the planning level to promote diversification and allocating 8.9 percent of total agricultural budget to this during the Fifth Five Year Plan (1997–2002) is a step in the right direction. Another key policy implication is investment in the development of rural infrastructure, which will not only increase the technical efficiency of the farmers but will also complement crop diversification by improving opportunities for technology diffusion, marketing, storage and resource supplies.

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References

Adesina. A.A., Zinnah, M.M. 1993. Technology characteristics, farmers' perceptions and adoption decisions: a tobit model application in Sierra Leone. *Agricultural Economics*. **9**: 297 – 311.

Ahmed, R. and Donovan, C. 1992. *Issues of infrastructural development: a synthesis of the literature*. International Food Policy Research Institute, Washington, D.C.

Ahmed, R. and Hossain, M. 1990. *Developmental impact of rural infrastructure in Bangladesh.* IFPRI Research Report 83. International Food Policy Research Institute, Washington, D.C.

Ali, M., Flinn, J.C. 1989. Profit efficiency among Basmati rice producers in Pakistan Punjab. *American Journal of Agricultural Economics*, **71**, 303 – 310.

Ali, F., Parikh, A., Shah, M.K. 1994. "Measurement of profit efficiency using behavioral and stochastic frontier approaches. *Applied Economics*, **26**, 181-188.

Arkin, H., Colton, R.R., 1963. *Tables for Statisticians*. 2nd Edition. Harper and Row Publishers, New York.

Asadullah, M.N., Rahman, S. 2008. "Farm productivity and efficiency in rural Bangladesh: the role of education revisited". *Applied Economics* (in press). doi: 10.1080/0003684060101925

Baidu-Forson, J. 1999. Factors influencing adoption of land-enhancing technology in the Sahel: lessons from a case study in Niger. *Agricultural Economics*, **20**: 231 – 239.

Battese, G.E., and Corra, G.S., 1977. Estimation of a production frontier model: with application to the pastoral zone of Eastern Australia. *Australian Journal of Agricultural Economics*, **21**: 161-179.

BBS, 1999. *Census of agriculture – 1996. Structure of Agricultural Holdings and Livestock Population*. Volume 1. Bangladesh Bureau of Statistics, Dhaka.

BBS, 2001. *Statistical Yearbook of Bangladesh, 2000*. Bangladesh Bureau of Statistics, Dhaka.

Bradshaw, B. 2004. Questioning Crop Diversification as a Response to Agricultural Deregulation in Saskatchewan, Canada. *Journal of Rural Studies,* **20**, 35-48.

Bravo-Ureta, B.E., Solis, D., Lopez, V.H.M., Maripani, J.F., Thiam, A., Rivas, T. 2007. Technical efficiency in farming: a meta regression analysis. *Journal of Productivity Analysis*, **27**:57-72.

Coelli, T.J., Fleming, E., 2004. Diversification economies and specialization efficiencies in a mixed food and coffee smallholder farming system in Papua New Guinea. *Agricultural Economics*, **31**: 229-239.

Coelli, T.J., Perelman, S., 1999. A comparison of parametric and non-parametric distance functions: with application to European railways. *European Journal of Operational Research*, **117**: 326-339.

Coelli, T.J., Rahman, S., Thirtle, C., 2002. Technical, allocative, cost and scale efficiencies in Bangladesh rice cultivation: a non-parametric approach. *Journal of Agricultural Economics*, **53**: 607-626.

Delgado, C.L. 1995. Agricultural diversification and export promotion in sub-Saharan Africa. *Food Policy*, **20**: 225-243.

Evenson, R.E., 1986. Infrastructure, output supply and input demand in Philippine agriculture: provisional estimates. *Journal of Philippine Development*, **13**: 62-76.

FAO, 2001. *Supplements to the Report on the 1990 World Census of Agriculture. Statistical Department Series (9a)*. Food and Agriculture Organisation, Rome. http://www.fao.org/es/ess/census/wcahome.htm

Guvele, C.A. 2001. Gains from crop diversification in the Sudan Gezira scheme. *Agricultural Systems*, **70**: 319-333.

Haji, J. 2007. Production efficiency of smallholders' vegetable-dominated mixed farming system in Eastern Ethiopia: a non-parametric approach. *Journal of African Economies*, **16**:1-27.

Hossain, M., Quasem, M.A., Akash, M.M., Jabber, M.A., 1990. Differential impact of modern rice technology: the Bangladesh case. Bangladesh Institute of Development Studies, Dhaka.

Hossain, M.S., Rahman, M.M., Harun-ur-Rashid, M., Farid, A.T.M., Quayyum, M.A., Ahmed, M., Alam, M. S., and Hussain, K.M.S.U., 2006. *Krishi Projukti Hatboi* (Handbook of Agro-technology). 4th Edition. Bangladesh Agricultural Research Institute, Gazipur, Bangladesh.

Husain, A.M.M., Hossain, M., Janaiah, A. 2001. *Hybrid Rice Adoption in Bangladesh: Socio-economic Assessment of Farmers' Experiences.* BRAC Research Monograph Series No. 18. Dhaka: BRAC, Bangladesh.

Kar, G., Singh, R., Verma, H.N. 2004. Alternative cropping strategies for assured and efficient crop production in upland rainfed rice areas of Eastern India based on rainfall analysis. *Agricultural Water Management*, **67**: 47-62.

Kodde, D., Palm, F. 1986. Wald criteria for jointly testing equality and inequality restrictions, *Econometrica*, **54**, 1243-1248.

Kumbhakar, S.S., Orea, L. Rodriguez-Alvarez, A. Tsonias, E. G. 2007. Do we estimate an input or an output distance function? An application of the mixed approach to European railways. *Journal of Productivity Analysis*, **27**: 87–100.

Llewelyn, R.V., Williams, J.R., 1996. Nonparametric analysis of technical, pure technical, and scale efficiencies for food crop production in East java, Indonesia. *Agricultural Economics*, **15**: 113-126.

Mahmud, W., Rahman, S.H., Zohir, S., 1994. *Agricultural growth through crop diversification in Bangladesh.* Food Policy in Bangladesh Working Paper No. 7. International Food Policy Research Institute, Washington, D.C.

MoA., 1989. Crop diversification program for the Fourth Five-Year Plan of Bangladesh. Agriculture Division, Ministry of Agriculture, Dhaka.

MoFA, 1962. *Pakistan Census of Agriculture – 1960. Final Report: East Pakistan*. Volume 1. Agricultural Census Organization, Ministry of Food and Agriculture, Government of Pakistan. Karachi.

Morris, M., Chowdhury, N., Meisner, C. 1996. Economics of wheat production in Bangladesh. *Food Policy*, **21**: 541 – 560.

Pawitan, Y. 2001. *In all Likelihood: Statistical Modelling and Inference Using Likelihood*. Clarendon Press, Oxford.

PC, 1998. *The Fifth Five Year Plan (1997-2002).* Ministry of Planning, Government of Bangladesh, Dhaka.

Rahman, S. 1998. Socio-economic and environmental impacts of technological change in Bangladesh agriculture. Unpublished PhD dissertation. Asian Institute of Technology, Bangkok, Thailand.

Rahman, S. 2005. Environmental impacts of technological change in Bangladesh agriculture: farmers' perceptions, determinants and effect on resource allocation decisions. *Agricultural Economics.* **33**: 107–116.

Rahman, S. and Parkinson, R.J. 2007. Soil fertility and productivity relationships in rice production system, Bangladesh. *Agricultural Systems.* **92**: 318-333.

Rahman, S., 2003. Profit efficiency among Bangladeshi rice farmers. *Food Policy*, **28**: 487-503.

STATA Corp, 2003. *Stata Statistical Software: Release 8.0.* Stata Corporation. College Station, Texas.

Toufique, K.A. 2001. *Structural constraint to agricultural growth: an explanation of the farm size productivity relationship in Bangladesh*. Working Paper. Bangladesh Institute of Development Studies, Dhaka.

Van den Berg, M.M., Hengsdijk, H., Wolf, J., Ittersum, M.K.V., Guanghuo, W., Roetter, R.P. 2007. The impact of increasing farm size and mechanization on rural income and rice production in Zhejiang province, China. *Agricultural Systems*, **94**: 841-850.

Wadud, M.A., White, B. 2000. Farm household efficiency in Bangladesh: a comparison of stochastic frontier and DEA methods. *Applied Economics*, **32**: 1665-1673.

Wang, J., Cramer, G.L., Wailes, E.J. 1996. Production efficiency of Chinese agriculture: evidence from Rural Household Survey data. *Agricultural Economics*, **15**, 17 – 28.

Table 1. Changes in cropped area, cropping intensity and diversification (1960 and 1996).

Indicators	**Census 1960**	**Census 1996**	**Inter-census change (%)**
Number of farms	6,139,480	11,798,242	92.17
% of small farms (0.02 – 1.01 ha)	51.63	79.87	197.26
% of medium farms (1.01 – 3.03 ha)	37.68	17.61	-10.19
% of large farms (above 3.03 ha)	10.69	2.52	-54.63
Operated area (ha)	7,744,929	8,076,369	4.28
Net temporary cropped area (ha)	7,627,372	6,655,771	-12.74
Gross cropped area (ha)	11,283,169	11,580,666	2.64
Operated area per farm (ha)	1.26	0.68	-45.74
Net temporary cropped area per farm (ha)	1.24	0.56	-54.59
Gross cropped area per farm (ha)	1.84	0.98	-46.59
Proportion of cropped area under (%)			
Rice	75.76	72.80	-1.37
Wheat and other minor cereals	0.82	5.52	585.35
Pulses	6.31	4.63	-24.72
Oilseeds	2.82	4.14	50.92
Cash crops	8.74	6.32	-25.77
Vegetables	2.22	3.55	64.49
Spices and other miscellaneous crops	3.33	3.04	-6.34
All non-cereals	23.42	21.68	-1.74
Cropping intensity (all farms)	148	174	26.00
Small farms	167	187	20.00
Medium farms	152	171	19.00
Large farms	135	154	19.00
Herfindahl index of crop diversification (all farms)	0.59	0.54	-4.50
Small farms	0.57	0.52	-4.59
Medium farms	0.59	0.55	-4.23
Large farms	0.60	0.59	-0.79

Source: Computed from BBS (1999) and MoFA (1962).

Table 2. Summary statistics of the variables per farm

Variable	Measure	Mean	Standard deviation
Inputs			
Land area cultivated (X_1)	Hectare	0.98	1.02
Labour (X_2)	Person days	81.99	69.29
Animal power services (X_3)	Animal pair-days	25.80	25.91
Fertilizer (X_4)	Kg	212.37	227.67
Irrigation (X_5)	Taka	1553.31	2422.88
Pesticides (X_6)	Taka	293.58	407.74
Seed (X_7)	Taka	102.12	118.18
Outputs			
Traditional rice (Y_1)	Kg	865.35	1416.77
Modern rice (Y_2)	Kg	2126.88	2564.43
Modern wheat (Y_3)	Kg	102.46	296.73
Cash crops[a] (Y_4)	Taka	3777.49	7984.99
Farm-specific variables			
Amount of owned land (Z_1)	Hectare	0.65	0.77
Education of farmer (Z_2)	Completed years of schooling	3.74	4.26
Experience (Z_3)	Years	25.51	14.21
Family size (Z_4)	Persons	6.02	2.53
Infrastructure index (Z_5)	Number	33.32	14.95
Soil fertility index (Z_6)	Number	1.68	0.19
Extension contact (Z_7)	1 if had contact, 0 otherwise	0.13	0.33
Non-agricultural income (Z_8)	Proportion of total income	0.22	0.31
Herfindahl index of crop diversification (Z_9)	Number	0.60	0.27
Number of observations		406	

Note: [a] = Includes jute, pulses, oilseeds, spices, potatoes and vegetables. The gross value of each output is used to construct this compound/aggregate variable, and is expressed in Taka.

Table 3. Parameter estimates of the stochastic input distance functions including inefficiency effects.

Variables	Parameters	Coefficients	S.E.
Production Variables			
Constant	α_0	1.2877	0.0584
ln(Fertilizers/Land)	α_2	0.2425	0.0600
ln(Labour/Land)	α_3	-0.0348	0.0918
ln(Animal/Land)	α_4	0.1908	0.0590
ln(Irrigation/Land)	α_5	0.0680	0.0173
ln(Pesticides/Land)	α_6	0.0056	0.0124
ln(Seeds/Land)	α_7	0.1231	0.0419
½ ln(Fertilizers/Land)^2	α_{22}	0.2678	0.1267
½ ln(Labour/Land)^2	α_{33}	0.2121	0.2981
½ ln(Animal/Land)^2	α_{44}	0.1183	0.0620
½ ln(Irrigation/Land)^2	α_{55}	0.0170	0.0063
½ ln(Pesticides/Land)^2	α_{66}	0.0076	0.0074
½ ln(Seeds/Land)^2	α_{77}	0.0086	0.0821
ln(Fertilizers/Land) x ln(Labour/Land)	α_{23}	-0.2145	0.3536
ln(Fertilizers/Land) x ln(Animal/Land)	α_{24}	-0.1377	0.2148
ln(Fertilizers/Land) x ln(Irrigation/Land)	α_{25}	-0.0555	0.0368
ln(Fertilizers/Land) x ln(Pesticides/Land)	α_{26}	-0.0556	0.0318
ln(Fertilizers/Land) x ln(Seeds/Land)	α_{27}	-0.0184	0.1641
ln(Labour/Land) x ln(Animal/Land)	α_{34}	0.4121	0.2687
ln(Labour/Land) x ln(Irrigation/Land)	α_{35}	-0.0242	0.0306
ln(Labour/Land) x ln(Pesticides/Land)	α_{36}	0.0501	0.0333
ln(Labour/Land) x ln(Seeds/Land)	α_{37}	0.1343	0.1819
ln(Animal/Land) x ln(Irrigation/Land)	α_{45}	0.0086	0.0556
ln(Animal/Land) x ln(Pesticides/Land)	α_{46}	-0.0413	0.0570
ln(Animal/Land) x ln(Seeds/Land)	α_{47}	0.5016	0.2784
ln(Irrigation/Land) x ln(Pesticides/Land)	α_{56}	0.0018	0.0070
ln(Irrigation/Land) x ln(Seeds/Land)	α_{57}	-0.0006	0.0308
ln(Pesticides/Land) x ln(Seeds/Land)	α_{67}	-0.0196	0.0308
ln(Traditional rice)	β_1	-0.1073	0.0077
ln(Modern rice)	β_2	-0.4195	0.0175
ln(Modern wheat)	β_3	0.0087	0.0185
ln(Cash crops)	β_4	-0.2449	0.0161
½ ln(Traditional rice)^2	β_{11}	-0.0635	0.0061
½ ln(Modern rice)^2	β_{22}	-0.1040	0.0062
½ ln(Modern wheat)^2	β_{33}	-0.0484	0.0109
½ ln(Cash crops)^2	β_{44}	-0.0499	0.0045
ln(Traditional rice) x ln(Modern rice)	β_{12}	0.0237	0.0045
ln(Traditional rice) x ln(Modern wheat)	β_{13}	0.0123	0.0044
ln(Traditional rice) x ln(Cash crops)	β_{14}	0.0262	0.0032
ln(Modern rice) x ln(Modern wheat)	β_{23}	0.0063	0.0044
ln(Modern rice) x ln(Cash crops)	β_{24}	0.0377	0.0036
ln(Modern wheat) x ln(Cash crops)	β_{34}	0.0125	0.0028
ln(Fertilizers/Land) x ln(Traditional rice)	τ_{21}	-0.0236	0.0113
ln(Fertilizers/Land) x ln(Modern rice)	τ_{22}	-0.0213	0.0171
ln(Fertilizers/Land) x ln(Modern wheat)	τ_{23}	-0.0350	0.0169

Variables	Parameters	Coefficients	S.E.
ln(Fertilizers/Land) x ln(Cash crops)	τ_{24}	0.0095	0.0102
ln(Labour/Land) x ln(Traditional rice)	τ_{31}	0.0287	0.0194
ln(Labour/Land) x ln(Modern rice)	τ_{32}	-0.0552	0.0315
ln(Labour/Land) x ln(Modern wheat)	τ_{33}	0.0417	0.0283
ln(Labour/Land) x ln(Cash crops)	τ_{34}	-0.0254	0.0166
ln(Animal/Land) x ln(Traditional rice)	τ_{41}	0.0175	0.0113
ln(Animal/Land) x ln(Modern rice)	τ_{42}	0.0092	0.0148
ln(Animal/Land) x ln(Modern wheat)	τ_{43}	0.0024	0.0153
ln(Animal/Land) x ln(Cash crops)	τ_{44}	0.0113	0.0101
ln(Irrigation/Land) x ln(Traditional rice)	τ_{51}	-0.0008	0.0022
ln(Irrigation/Land) x ln(Modern rice)	τ_{52}	0.0033	0.0027
ln(Irrigation/Land) x ln(Modern wheat)	τ_{53}	0.0041	0.0031
ln(Irrigation/Land) x ln(Cash crops)	τ_{54}	-0.0012	0.0020
ln(Pesticides/Land) x ln(Traditional rice)	τ_{61}	-0.0035	0.0019
ln(Pesticides/Land) x ln(Modern rice)	τ_{62}	-0.0039	0.0033
ln(Pesticides/Land) x ln(Modern wheat)	τ_{63}	0.0018	0.0023
ln(Pesticides/Land) x ln(Cash crops)	τ_{64}	0.0007	0.0013
ln(Seeds/Land) x ln(Traditional rice)	τ_{71}	0.0135	0.0106
ln(Seeds/Land) x ln(Modern rice)	τ_{72}	0.0032	0.0119
ln(Seeds/Land) x ln(Modern wheat)	τ_{73}	-0.0204	0.0134
ln(Seeds/Land) x ln(Cash crops)	τ_{74}	0.0002	0.0089
Model diagnostics			
Gamma	γ	0.6218	0.1277
Sigma-squared	σ_s^2	0.0672	0.0105
Log likelihood		45.7322	
$\chi^2_{(65,0.99)}$		5783.12	
Inefficiency effects function			
Constant	δ_0	-2.5976	-0.7058
Amount of land owned	δ_1	0.0867	0.0603
Education of farmer	δ_2	0.0008	0.0094
Farming experience	δ_3	0.0032	0.0020
Family size	δ_4	0.0177	0.0126
Infrastructure index	δ_5	0.0064	0.0018
Soil fertility index	δ_6	0.0315	0.1651
Extension contact	δ_7	-0.0468	0.1095
Share of non-agricultural income	δ_8	-0.0524	0.0840
Herfindahl index of crop diversification	δ_9	2.7910	0.6156

Table 4. Economies of diversification

Crop enterprise combinations	Parameter	Coefficient	S.E.
Traditional rice and modern rice	$\hat{\omega}_{12}$	0.0118	0.0022
Traditional rice and modern wheat	$\hat{\omega}_{13}$	0.0062	0.0022
Traditional rice and cash crops	$\hat{\omega}_{14}$	0.0131	0.0016
Modern rice and modern wheat	$\hat{\omega}_{23}$	0.0032	0.0022
Modern rice and cash crops	$\hat{\omega}_{24}$	0.0189	0.0018
Modern wheat and cash crops	$\hat{\omega}_{34}$	0.0062	0.0014

Note: The null-hypothesis is that there is no diversification of economies, ($\frac{\partial^2 \ln D}{\partial \ln Y_k \partial \ln Y_l} = 0, \ \forall \ k \neq l$).

For details of derivation of these estimates and their standard errors, see Appendix A.

Table 5. Input use rates per hectare by type of farms

Variables	**Diversified farms**	**Specialized farms**	**Mean difference (Diversified vs. Specialized)**	**t-ratio**
Land area cultivated (ha)	1.17	0.53	0.56	4.99***
Labor (days/ha)	92.62	123.86	-31.24	-6.85***
Animal power services (pair-days/ha)	26.34	30.37	-4.04	-4.45***
Fertilizer (kg/ha)	212.37	262.74	-50.37	-6.30***
Pesticides (Taka/ha)	315.81	672.90	-357.12	-6.32***
Irrigation (Taka/ha)	1,587.16	1,528.68	58.47	0.44
Seed (kg/ha)	115.49	108.12	7.37	0.73
Gross value of output (Taka/ha)	22,164.46	24,470.43	-2,305.86	-2.99***
Profits (Taka/ha)	12,616.01	13,202.84	-586.83	-0.82
Technical efficiency score	0.95	0.52	0.43	52.62***
Number of farms	299	107		

Note: Profits = (gross value of output – variable cost of all inputs)
*** = significant at 1 percent level (p<0.01)

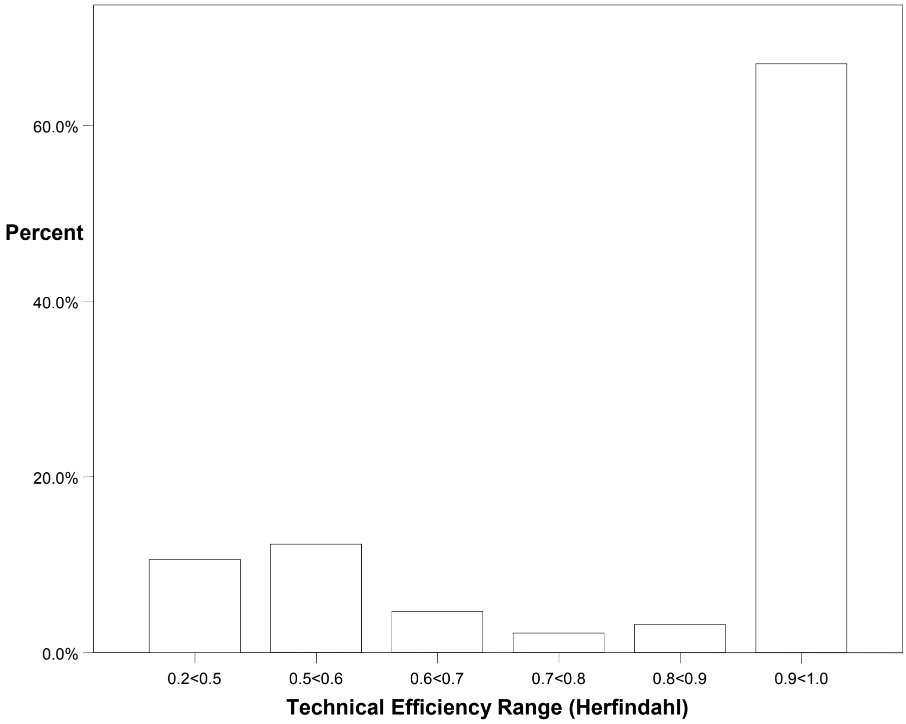

Figure 1. Distribution of technical efficiency indices.

Appendix A

After estimation, Eq. (5) can be written as:

$$-\ln X_1 = \hat{\alpha}_0 + \sum_{i=2}^{7} \hat{\alpha}_i \ln\left(\frac{X_i}{X_1}\right) + \frac{1}{2}\sum_{i=2}^{7}\sum_{j=2}^{7} \hat{\alpha}_{ij} \ln\left(\frac{X_i}{X_1}\right)\ln\left(\frac{X_j}{X_1}\right) + \sum_{k=1}^{4} \hat{\beta}_k \ln Y$$
$$+\frac{1}{2}\sum_{k=1}^{4}\sum_{l=1}^{4} \hat{\beta}_{kl} \ln Y_k \ln Y_l + \sum_{i=2}^{7}\sum_{k=1}^{4} \hat{\tau}_{ik} \ln\left(\frac{X_i}{X_1}\right)\ln Y_k + \hat{v} - \hat{u} \qquad (A1)$$

Replacing $(\hat{v} - \hat{u})$ with –ln*D* gives:

$$-\ln X_1 = \hat{\alpha}_0 + \sum_{i=2}^{7} \hat{\alpha}_i \ln\left(\frac{X_i}{X_1}\right) + \frac{1}{2}\sum_{i=2}^{7}\sum_{j=2}^{7} \hat{\alpha}_{ij} \ln\left(\frac{X_i}{X_1}\right)\ln\left(\frac{X_j}{X_1}\right) + \sum_{k=1}^{4} \hat{\beta}_k \ln Y$$
$$+\frac{1}{2}\sum_{k=1}^{4}\sum_{l=1}^{4} \hat{\beta}_{kl} \ln Y_k \ln Y_l + \sum_{i=2}^{7}\sum_{k=1}^{4} \hat{\tau}_{ik} \ln\left(\frac{X_i}{X_1}\right)\ln Y_k - \ln D \qquad (A2)$$

Re-arranging gives:

$$\ln D = \hat{\alpha}_0 + \sum_{i=2}^{7} \hat{\alpha}_i \ln\left(\frac{X_i}{X_1}\right) + \frac{1}{2}\sum_{i=2}^{7}\sum_{j=2}^{7} \hat{\alpha}_{ij} \ln\left(\frac{X_i}{X_1}\right)\ln\left(\frac{X_j}{X_1}\right) + \sum_{k=1}^{4} \hat{\beta}_k \ln Y$$
$$+\frac{1}{2}\sum_{k=1}^{4}\sum_{l=1}^{4} \hat{\beta}_{kl} \ln Y_k \ln Y_l + \sum_{i=2}^{7}\sum_{k=1}^{4} \hat{\tau}_{ik} \ln\left(\frac{X_i}{X_1}\right)\ln Y_k + \ln X_i \qquad (A3)$$

Taking the first partial derivative of Eq. (A3) with respect to Y_k gives:

$$\frac{\partial \ln D}{\partial \ln Y_k} = \sum_{k=1}^{4} \hat{\beta}_k + \frac{1}{2}\sum_{k=1}^{4}\sum_{l=1}^{4} \hat{\beta}_{kl} \ln Y_l + \sum_{i=2}^{7}\sum_{k=1}^{4} \hat{\tau}_{ik} \ln\left(\frac{X_i}{X_1}\right) \qquad (A4)$$

Taking the second partial derivative of Eq. (A4) with respect to Y_l (for all $k \neq l$) gives:

$$\frac{\partial \ln D}{\partial \ln Y_k \partial \ln Y_l} = \frac{1}{2}\sum_{k=1}^{4}\sum_{l=1}^{4} \hat{\beta}_{kl} = \hat{\omega}_{kl} \qquad (\forall\ k \neq l) \qquad (A5)$$

The standard error (S.E.) of $\hat{\omega}_{kl}$ can be obtained by applying the '*delta method*' as follows.

In view of the central limit theorem, the '*delta method*' applies to functions of sample mean. Informally, we can say that $h(\hat{\omega}_{kl})$ is approximately normal with mean $h(\omega)$ and variance $|h'(\omega_{kl})|^2\ \mathrm{var}(\hat{\omega}_{kl})$ (Pawitan, 2001).

Applying this method, therefore, gives:

$$Var(\hat{\omega}_{kl}) = Var(\frac{1}{2}\hat{\beta}_{kl}) = | h'(\omega_{kl}) |^2 \ \mathrm{var}(\hat{\omega}_{kl}) = \frac{1}{4} Var(\hat{\beta}_{kl}) \qquad (A6)$$

which is equivalent to:

$$S.E.(\hat{\omega}_{kl}) = \frac{1}{2} S.E.(\hat{\beta}_{kl}) \qquad (A7)$$